MTF-Derived Image Metric for the Performance of Laser-Based Imaging Systems

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LONG-TERM GOALS

The long-term goal of this project is to derive a general and comprehensive algorithm to calculate a scalar image metric which will help quantify the performance of emerging laser-based imaging systems in the highly variable optical littoral environment. After validation, this image metric will then be used to assist in mission planning by providing up-to-date maps of the expected system performance for each of these imaging platforms along littoral routes and areas of interest to the Navy.

OBJECTIVES

The objective of this project is to develop a scalar image metric based on the optical properties of the water column at the time a laser-based imaging system is deployed. The desired image metric should incorporate the deleterious effects on imaging due to the optical environment such as forward scattering, backscattered light and, as in the case of the Streak Tube Imaging Lidar (STIL), shot noise image corruption caused by low signal return. Another objective is to incorporate system-based loss of information into the image metric, such as that due to increasing either the size of the pixel footprint on the scene to be imaged or the laser spot size for the case of the Laser Line Scanner (LLS).

APPROACH

The performance of a laser-based imaging system depends both on the properties of the water column in which it is immersed and on adjustable system variables such as source and receiver parameters. These systems output a 2-D image of the ocean floor and performance models already exist which can simulate the expected imagery and display it on a monitor. Most of these models use the Modulation Transfer Function (MTF) to simulate the predicted imagery. From Fourier theory, clear 2-D images can be decomposed into the sum of sinusoidal radiance patterns at many different frequencies. The MTF contains information about how much each of these sinusoidal patterns of radiance is attenuated by the optical environment and by the system characteristics. The attenuated sinusoidal patterns of radiance are then recombined to produce the expected 2-D imagery.

What is needed for mission planning, however, is to develop the capability for these MTF-based performance models to associate a number, a scalar image metric, to the expected quality of the imagery output from a system. Ideally, this number should follow a scale from 0.0 to an arbitrary maximum for “crystal clear imagery”.

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The approach here is to use the shape of the MTF curve as an indicator of the quality of the expected imagery. The MTF is a sensitive function of spatial frequency and depends on optical properties of the water column such as the scattering coefficient, the mean scattering angle and the backscatter coefficient (see reference 1). Its shape also depends on the characteristics of the imaging system itself: its overall design, source beam spot size and receiver field of view (see reference 2). The MTF is also ideal for mission planning since it can quickly be evaluated over the range of spatial frequencies allowed by the imaging system.

As has previously been done in the past (see references 3 and 4), the area under the MTF curve (MTFA) can be used as a scalar image metric. Our approach is to refine the simple MTFA methodology of the past in several significant ways. First, a more exact expression for the combined effect of forward scattering and backscattering will be derived. Second, the threshold contrast function of the eye will be incorporated into the calculation of the area. Third, an interactive study of the effect of shot noise on the interpretation of system imagery will be performed and the results included as a reduction in the value of the area under the MTF. It is expected that this improved MTFA calculation will provide a scalar image metric sufficiently representative of predicted imagery that it can be used for quick, efficient mission planning.

The above MTF dependence on both the optical environment parameters and system characteristics therefore make it a logical choice and basis for the development of a scalar image metric. Once the algorithm to predict this metric has been developed, a study of its correlation with predicted imagery can be made. From this study, a threshold value can be established below which very poor imagery is expected. In operational scenarios, the image metric can be calculated in situ and a “go/no-go” decision can be made for system deployment, depending on the predicted value for the image metric under given optical conditions and “flying” altitude.

WORK COMPLETED

At this time, the project is on schedule. Presently, the metric incorporates the effects of the optical environment: forward scattering, mean scattering angle and backscattering and has been scaled from 0.0 to 1.0, although it is a simple matter to adapt it to any other scale, if needed. The MTF curve represents the effect of the environment and is calculated from the cascading property of the MTF:

$$MTF_{environment} = MTF_{forwscattering} MTF_{backscattering},$$

where $MTF_{forwscattering}$ is the MTF due to forward scattering, which depends on the mean scattering angle and scattering coefficient; $MTF_{backscattering}$ is the MTF due to backscattering and depends on the ratio of the average image radiance and the backscattered radiance. The backscattering acts as a uniform veil over the image and its effect is best illustrated when one turns on the lights in a movie theater, thereby reducing the overall perceived contrast of the image on the screen.

In order to check whether the value of the scalar image metric changes in a consistent manner as the scattering characteristics of the water column change over their respective ranges of values, an interactive GUI was created. It contains a 2-D reference image with very fine detail which is blurred with the help of the MTF (see reference 5) and serves as a visual check on the correlation between the degradation of the image and the scalar image metric value associated with that degradation.

RESULTS

Preliminary results from using the interactive GUI for the image metric due to only forward and back scattering have been obtained. These indicate that the scalar image metric derived from the MTFA varies in a consistent manner and in direct correlation to the visually observed image degradation, as expected.

IMPACT/APPLICATIONS

The successful development of a scalar image metric to quantify imaging system performance will allow for efficient mission planning along pre-selected routes and transects in the littoral regions.

TRANSITIONS

None

RELATED PROJECTS

This project is directly related to predicting the performance of emerging laser-based imaging systems such as the Laser Line Scanner (LLS) and the Streak Tube Imaging Lidar (STIL).

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PUBLICATIONS

None

PATENTS

None